

A TOOL MEASURING REMAINING THICKNESS OF NOTCHED ACOUSTIC CAVITIES IN PRIMARY REACTION CONTROL THRUSTER NDI STANDARDS

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ABSTRACT. Stress corrosion cracking in the relief radius area of a space shuttle primary reaction control thruster is an issue of concern. The current approach for monitoring of potential crack growth is nondestructive inspection (NDI) of remaining thickness (RT) to the acoustic cavities using an eddy current or remote field eddy current probe. EDM manufacturers have difficulty in providing accurate RT calibration standards. Significant error in the RT values of NDI calibration standards could lead to a mistaken judgment of cracking condition of a thruster under inspection. A tool based on eddy current principle has been developed to measure the RT at each acoustic cavity of a calibration standard in order to validate that the standard meets the sample design criteria.

Keywords: space shuttle, thruster, stress corrosion cracking, calibration standard, EDM notch, remaining thickness, measurement tool

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INTRODUCTION

Stress corrosion cracking in the relief radius area of a space shuttle primary reaction control system (RCS) thruster is an issue of concern. The current approach for monitoring of potential crack growth is nondestructive inspection (NDI) of remaining thickness (RT) to the acoustic cavities using an Eddy Current (EC) or Remote Field Eddy Current (RFEC) probe.

NDI Standards with EDM notches of designed length, L , and notch orientation angle, θ , have been built for calibration of different NDI techniques to be used for the inspection. The designed RT can be calculated from the two parameters, L and θ , provided by a designer or a manufacturer as

$$RT = T - L * \cos(\theta), \quad (1)$$

where T is the axial distance from relief radius to acoustic cavity wall. EDM manufacturers are capable of controlling L precisely, typically certifying this notch length. However, they have difficulty in providing accurate control of θ in the EDM process. Normally they do not provide measurement data for θ in their certificates. Inaccuracy of θ introduces error in RT calculated from Equation (1). The error becomes significant when $RT \ll T$, especially for flaws at large angle θ . Significant error in RT values of NDI

calibration standards could lead to an incorrect judgment of cracking condition of a thruster under inspection.

A tool based on eddy current principle has been developed to measure the RT between fabricated EDM notches in a calibration standard and the adjacent acoustic cavities. It provides much more precise value of RT and would help with validating the RT values of EDM notches made on primary reaction control thruster NDI standards.

CRACK DETECTION IN PRIMARY REACTION CONTROL SYSTEM (RCS) THRUSTER STANDARDS

A typical RCS thruster standard is shown in Figure 1, [1]. The major portion of a thruster, called the injector, is located at the bottom of a thruster. Stress corrosion cracking on the exterior of the injector has been identified on several thrusters. A nozzle is welded on the top of the injector and the exterior of the thruster is not accessible for inspection. Inspection probe/tools have to be inserted into the nozzle through a 1.9" (48.26 mm) diameter narrow throat and reach into the acoustic cavities for inspection of this area.

There are two areas where stress corrosion cracking have been found: in the 16 counter bore holes and in the relief radius area as shown in Figure 2. As the major interest of this paper we are going to focus on the cracks in relief radius area. Figure 3A shows a crack initiating from the relief radius area and growing towards an acoustic cavity. Figure 3B shows an EC probe inserted in an acoustic cavity inspecting for a relief radius crack.

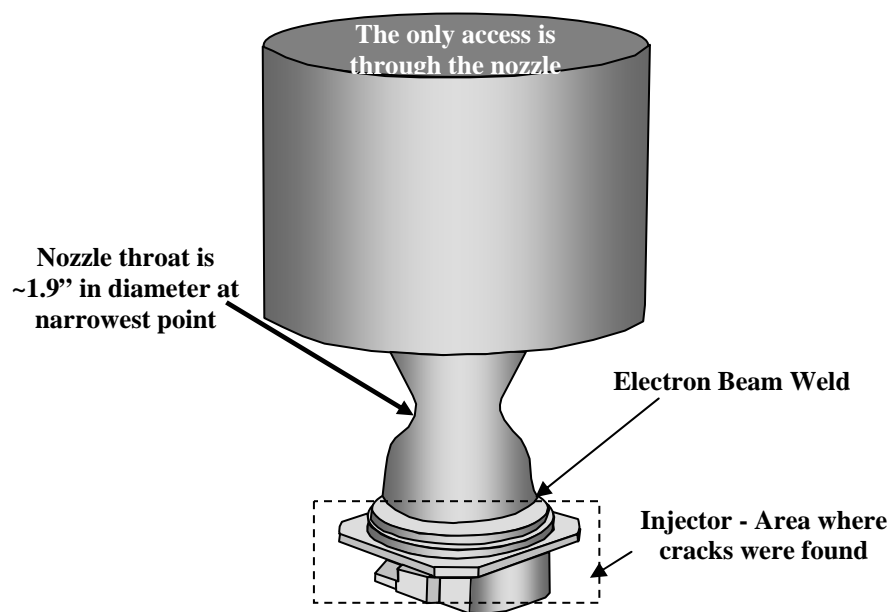


FIGURE 1. A typical RCS thruster.

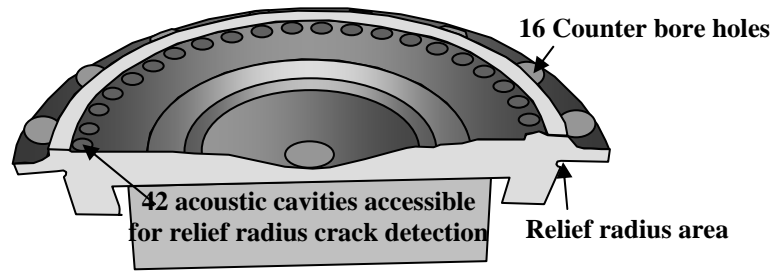


FIGURE 2. Areas where cracks were found

SIGNIFICANCE FOR ENSURING ACCURACY OF REMAINING THICKNESS (RT) IN RELIEF RADIUS AREA NDI STANDARDS

The requirement on RCS thruster relief radius crack detection is to ensure the RT is no less than 0.020", preferably with detection capabilities to 0.060" RT. The challenges are:

1. EDM manufacturers have difficulties in providing accurate control of θ in the EDM process.
2. Inaccuracies in θ result in an error in the RT calculated from Equation (1). The error becomes significant when $RT \ll T$, as shown in Figure 3. As an example, with wall thickness $T = 0.176"$, for an EDM notch with $L = 0.176"$ and $\theta = 60^\circ$, the designed RT is 0.020". However, if the fabricated angle θ is 58° , 2° smaller than the given value, 60° , the actual RT becomes 0.000". The EDM becomes a through-wall notch.
3. Error in RT values of NDI calibration standards would be misleading in NDI technique evaluation and lead to a potential for wrong call/rejection indications in NDI procedures.
4. Need exists for a tool for accurate measurement of RT of notched acoustic cavities in RCS thruster NDI standards.

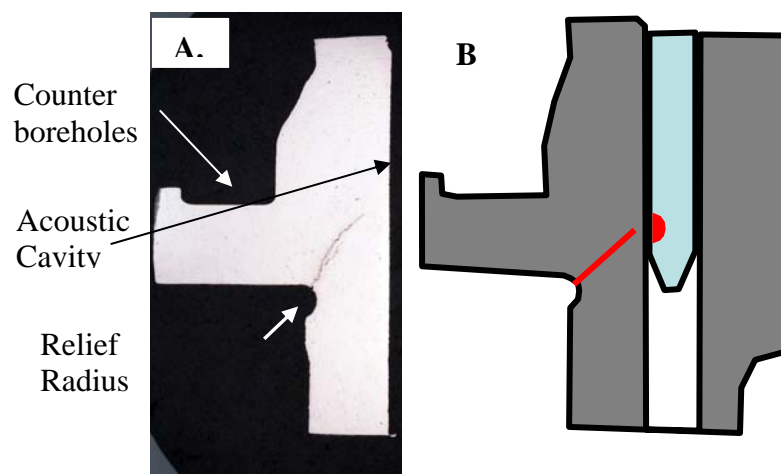


FIGURE 3. A: Crack extending from relief radius towards acoustic cavity. B: An EC probe inspecting a relief radius crack.

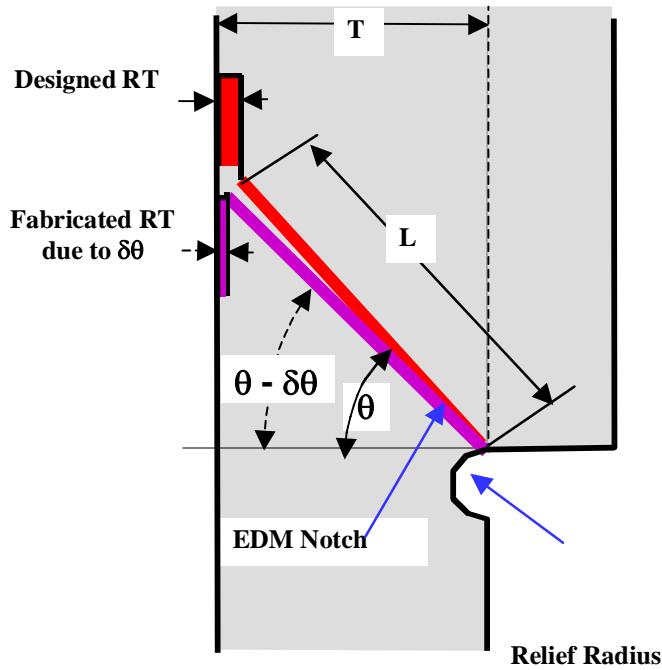


FIGURE 4: A small error in θ results significant difference of actual RT from its designed value.

A TOOL MEASURING REMAINING THICKNESS, RT

A tool based on eddy current principle is built for the purpose of measuring the RT at an acoustic cavity. A draft drawing of the tool is shown on Figure 5 (left). A drive coil is placed at relief radius area. The pickup coil is inserted into the cavity. A photo of the tool is shown in Figure 5 (right).

Our previous work [2] has proved that the electromagnetic energy released by an EC probe diffuses/propagates along an interface of a conductor or two conductors much faster than it diffuses inside a conductor. Therefore, we can assume the phase lag of the signal received by the pickup coil is primarily dominated by the energy diffusing through the RT. Thus, the signal phase lag measured by the pickup coil increases with increasing RT.

The tool pictured in Figure 5 has been used for measuring RTs of all the acoustic cavities of three thruster standards, including two oil bronze standards, OB STD 1 and OB STD 2, and a standard fabricated from a flown RCS thruster, STD #11/SN 714. The measurement results are shown on next few pages.

MEASUREMENT PROCEDURE

Two reference points are determined before a measurement: Reference Point #1 where a pickup coil does not receive any signal from the drive coil; Reference Point #2 when there is a through EDM notch in the cavity. For measuring Reference Point #1 the pickup coil can be placed anywhere far from the drive coil. The system is nulled at Reference Point #1.

To get a reference impedance curve from point #2 the pickup coil is inserted in a cavity with a through-wall EDM notch. The pickup coil is then scanned from cavity bottom to top. A curve appears on the system screen as shown by the dashed line in Figure 6. Next, the phase angle of the system is rotated to have a point of the curve to be tangent to

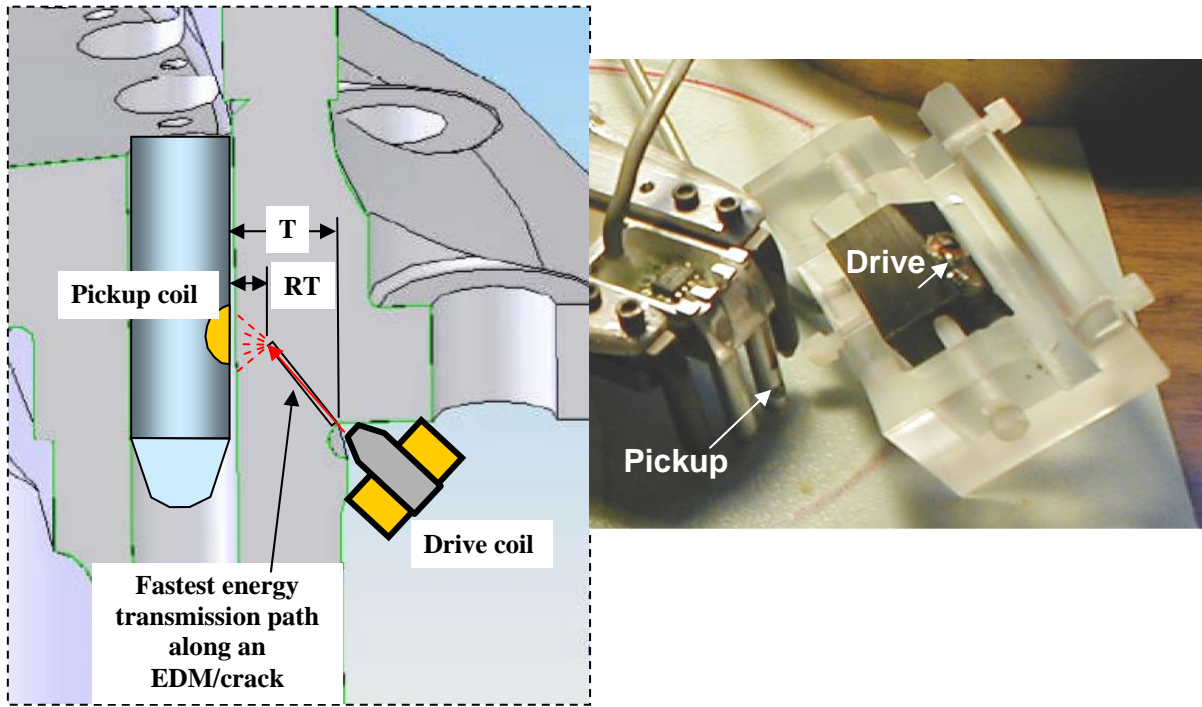


FIGURE 5. A draft drawing for the tool measuring RT of a cavity (left) and a photo of the tool (right).

the horizontal axis. This sets the phase of the minimum phase point of the curve to be zero, as shown by the solid line on Figure 6.

TEST RESULTS

The designed parameters of the EDM notches made on three standards are listed in Table 1. The impedance curves measured using the RT measurement tool are shown in Figures 7, 8 and 9.

OBSERVATIONS

Some inconsistencies have been seen between the measured RT values and the designed RT in all three standards. These include at least:

1. Designed RT for EDM #1 in OB STD 1 is 0.000". We do not see a through notch at this location and the measured impedance curve is very close to a curve of RT = 0.020".
2. EDM notches #2, #3 and #4 are all the same angle, 45°, and have equal-spaced RTs. As the phase angle is linear with RT [2], equally spaced impedance curves should be measured. However, the measured impedance curves are far from equal-spaced.
3. We see a through notch in OB STD 2 at EDM #9 where the designed RT = 0.020".
4. In STD #11 EDM notch #10 is located in between two cavities with a designed RT of 0.020" to each of the two adjacent cavities. Similarly there should be of RT = 0.040" for each of the two cavities adjacent to EDM notch #11. However, the RTs measured from the two cavities on either side of each notch are widely separated, indicating the two EDM notes are not equally spaced between the cavities.

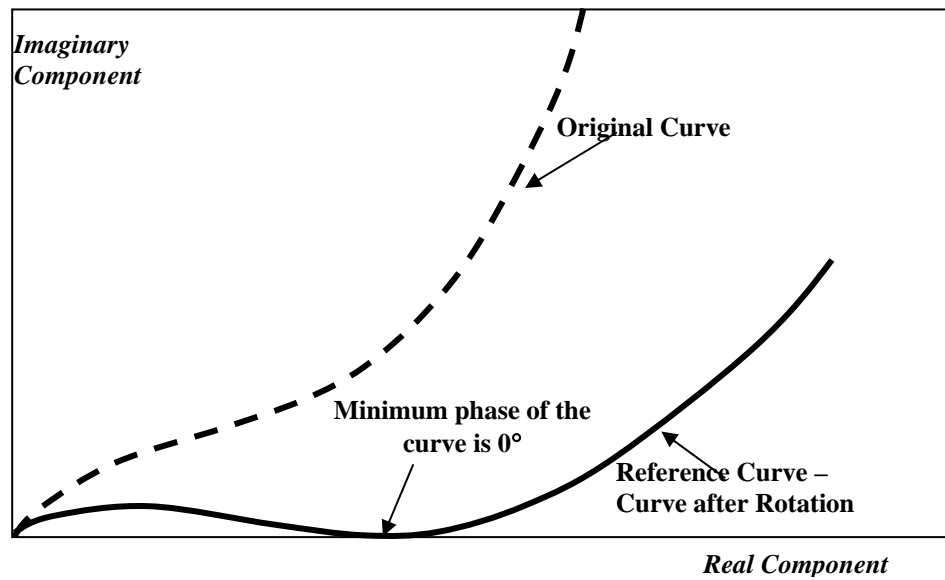


FIGURE 6. Set system rotation angle using Reference Point #2

TABLE 1. EDM parameters for all the EDM notches made on the three standards

Standard	Location	EDM #	Angle	Depth	Designed RT
OB STD 1	at a cavity	1	45°	0.247"	0.000"
OB STD 1	at a cavity	2	45°	0.219"	0.020"
OB STD 1	at a cavity	3	45°	0.190"	0.040"
OB STD 1	at a cavity	4	45°	0.162"	0.060"
OB STD 1	at a cavity	5	45°	0.134"	0.080"
OB STD 1	at a cavity	6	60°	0.229"	0.060"
OB STD 2	at a cavity	7	30°	0.179"	0.020"
OB STD 2	at a cavity	8	45°	0.219"	0.020"
OB STD 2	at a cavity	9	60°	0.309"	0.020"
OB STD 2	at a cavity	10	30°	0.155"	0.040"
OB STD 2	at a cavity	11	45°	0.190"	0.040"
OB STD 2	at a cavity	12	60°	0.269"	0.040"
OB STD 2	at a cavity	13	30°	0.132"	0.060"
OB STD 2	at a cavity	14	45°	0.162"	0.060"
STD #11	at AC 27	06	45°		0.020"
STD #11	at AC 32	07	45°		0.040"
STD #11	at AC 37	08	45°		0.060"
STD #11	at AC 16	09	60°		0.020"
STD #11	between AC05 & AC 06	10	45°		0.020"
STD #11	between AC 10 & AC11	11	30°		0.040"

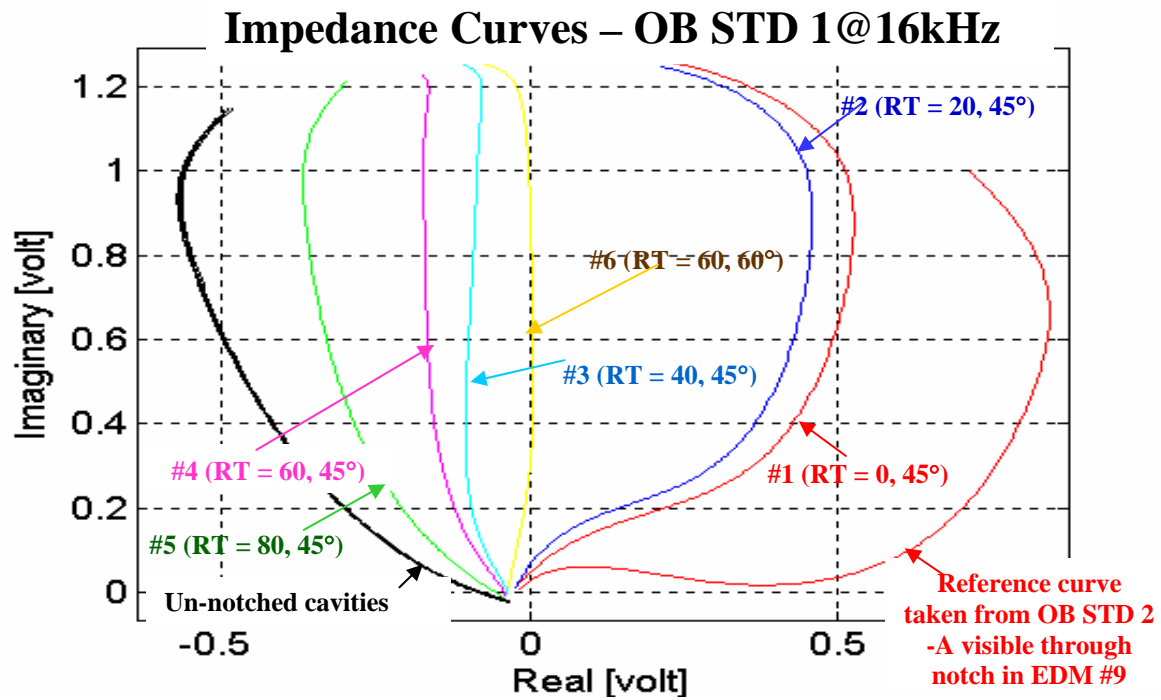


FIGURE 7. Impedance curves measured from OB STD 1 using the RT measurement tool.

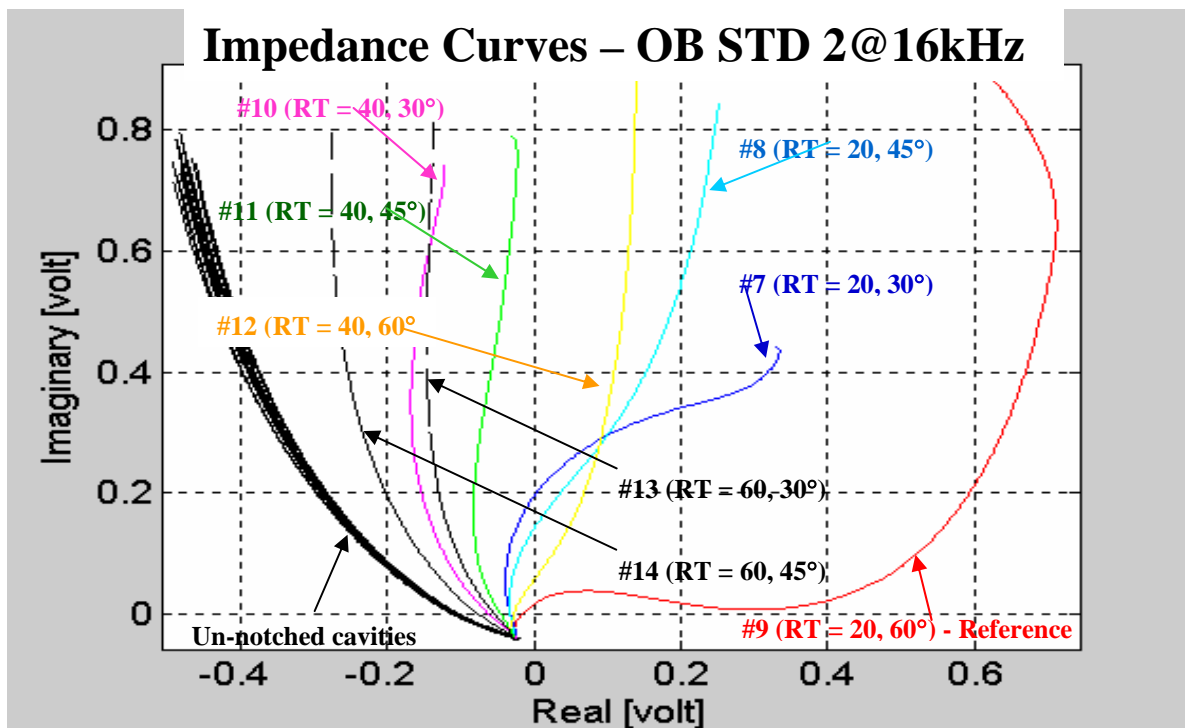


FIGURE 8. Impedance curves measured from OB STD 2 using the RT measurement tool.

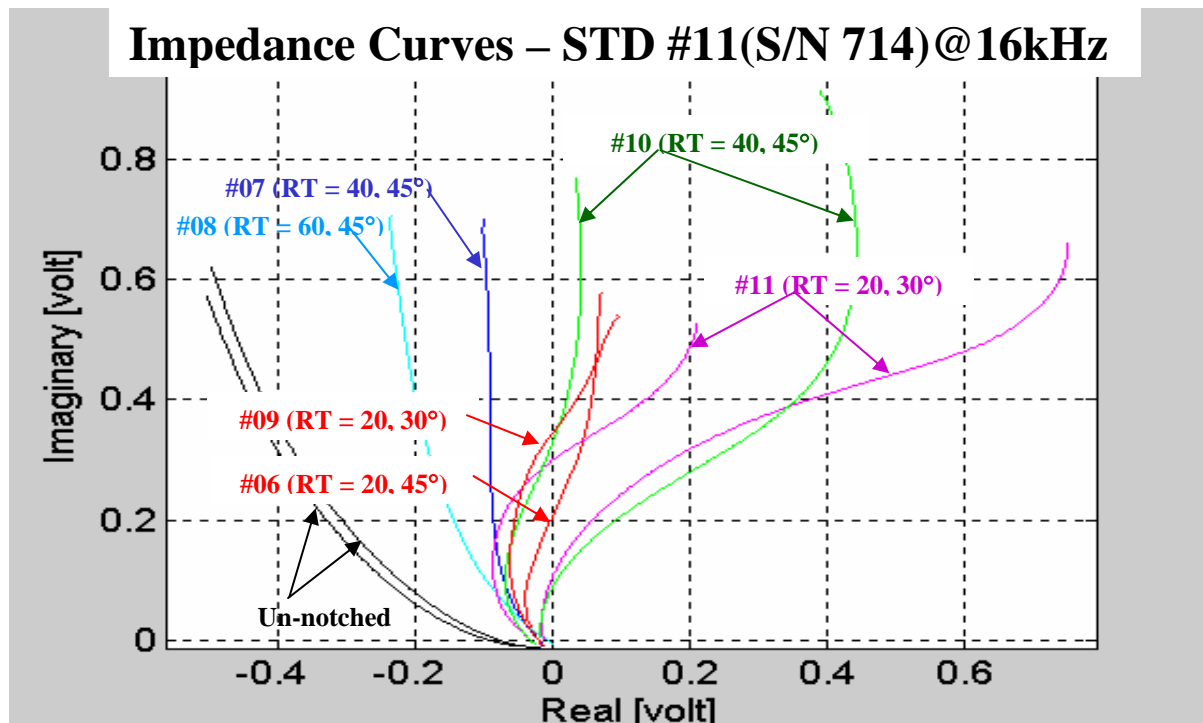


FIGURE 9. Impedance curves measured from STD #11/SN 714 using the RT measurement tool.

CONCLUSIONS

1. NDI of remaining thickness (RT) is a key to ensure safe working conditions for RCS thruster.
2. Manufacturers may not be capable of providing accurate RT values for EDM notches made in relief radius area of a thruster. Any errors in RT values of a thruster NDI standard would be misleading in thruster NDI.
3. It is a significant issue to find a way to measure the actual RT values of all EDM notches made in thruster NDI standards.
4. A prototype of an EC based tool measuring EDM notch RT values has been built and tested. The test results have shown some inconsistency between the measured RT values with the designed RT values.
5. Further study is necessary to verify the accuracy of the tool and improve its user friendliness.

REFERENCES

1. NESC White Paper "NASA Engineering and Safety Center Nondestructive Evaluation Technical Review of the Space Shuttle Primary Reaction Control Thruster Injector Crack Issue" (2005).
2. Y. Sun, *Materials Evaluation*, **47**, 87-92, (1989).